Recent developments for MiniCactus

CEA/Irfu/DphP and CEA/Irfu/Dedip

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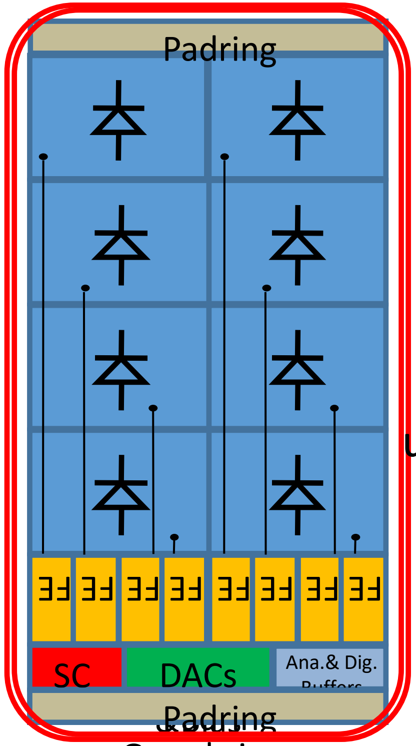
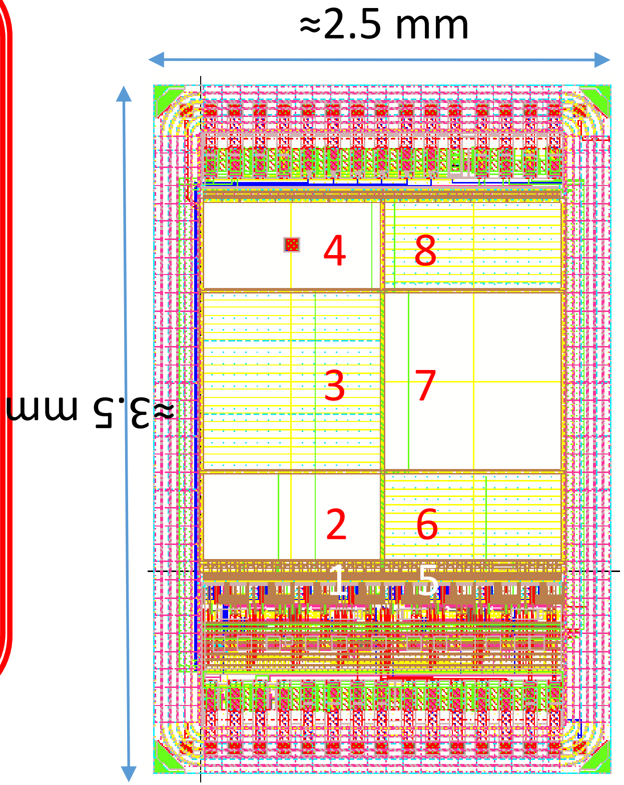
MiniCACTUS v1 Sensor Chip



Block diagram of the MiniCACTUS chip (not to scale)

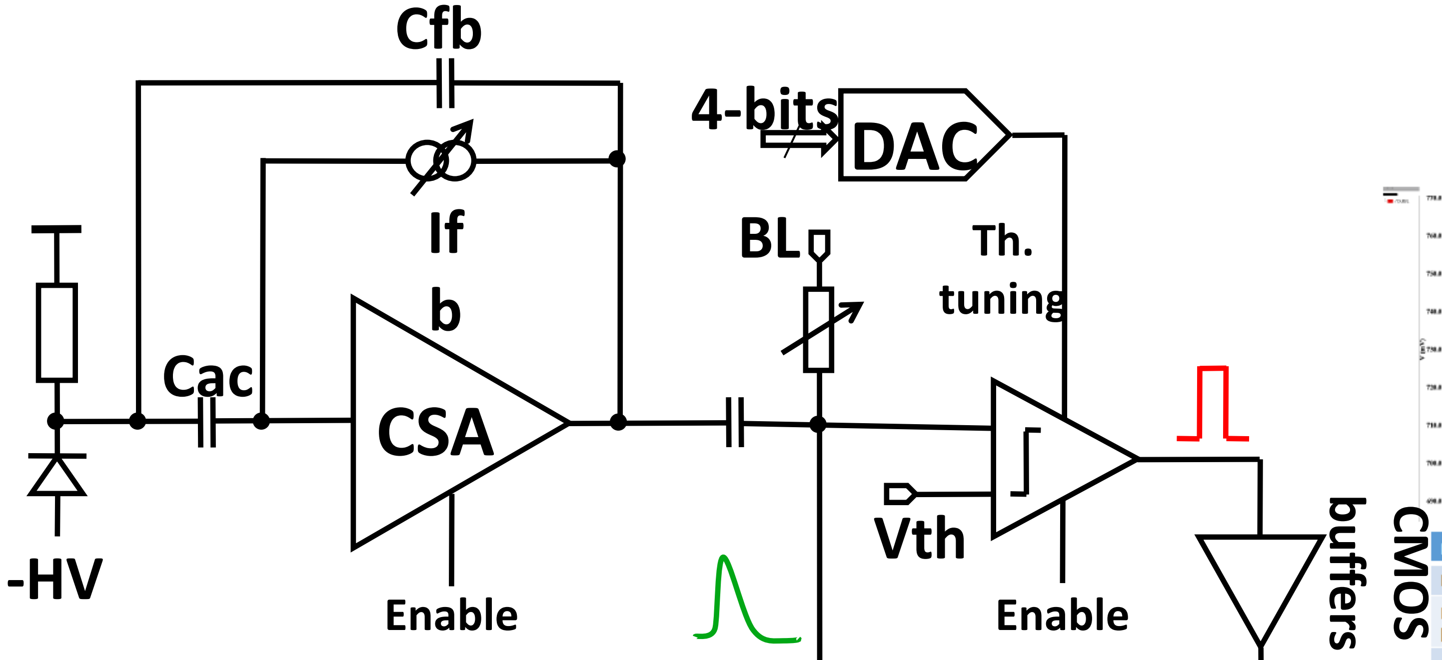


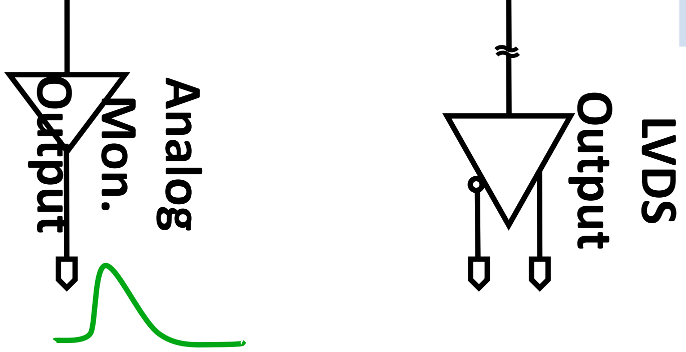
Layout of MiniCACTUS

Pixel Flavors :
Pixels 3 & 7 : 1 mm x 1 mm baseline pixels
Pixels 2, 4, 6 & 8 : 0.5 mm x 1 mm pixels
Pixel 8 : 0.5 mm x 1 mm pixel with in-pixel AC coupling capacitor (20pF)
Pixels 1 : 50 µm x 50 µm test pixel
Pixels 5 : 50 µm x 150 µm test pixel

- **MiniCACTUS** is a detector prototype designed in order to address the *low S/N issue* observed on previous CACTUS large size demonstrator
- Main change in MiniCACTUS: FE integrated at column level, pixels mostly passive
- On-chip **Slow Control**, **DACs**, **bias circuitry**
- 2 discriminated digital (LVDS) and 2 analog monitoring (*slower than CSA output*) outputs for 2 columns
- 2 small pixels implemented as test structures to study charge collection (*FEs not power optimized*)
- Some detectors thinned to 100, 200, 300µm and than post-processed for backside polarization after fabrication

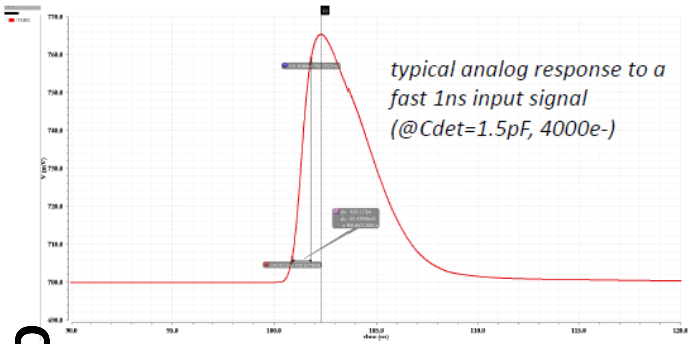
ON-CHIP FRONT-END





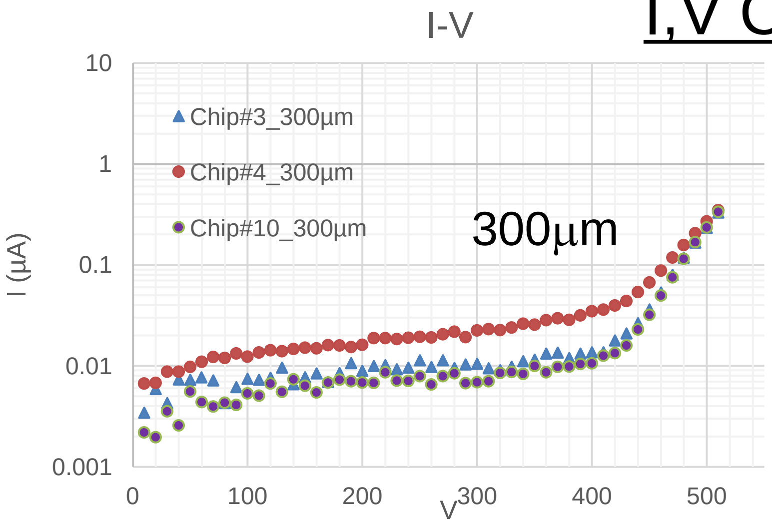
- ❑ Front-end mostly optimized for 1 mm² pixels with peaking time of 1-2 ns @ 1-2pF (Ibias_total=800µA → P ≈ 150mW/cm²)
- ❑ Architecture inspired from LF-CPIX & LF-MONOPIX chips

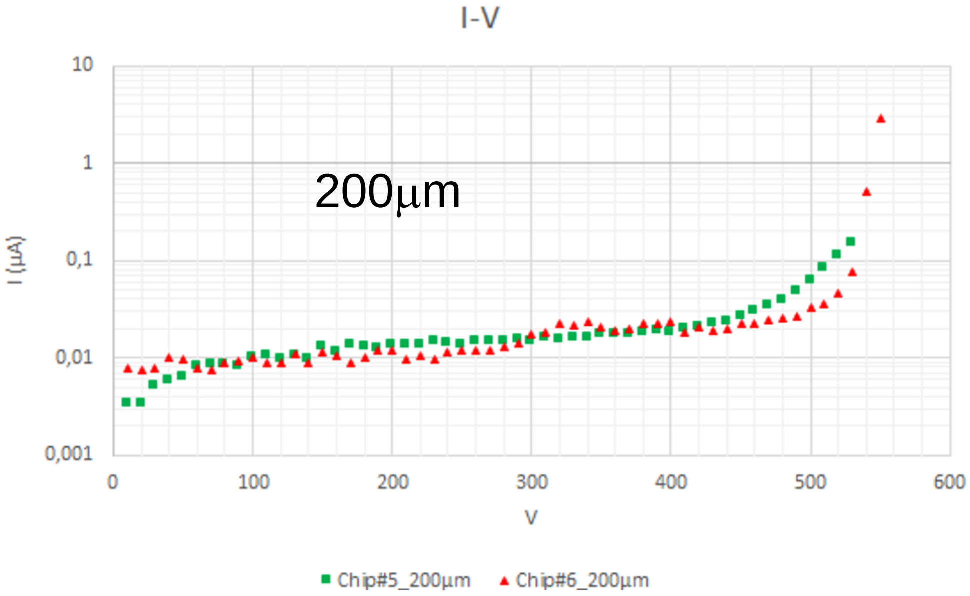
Typical CSA transient simulation result

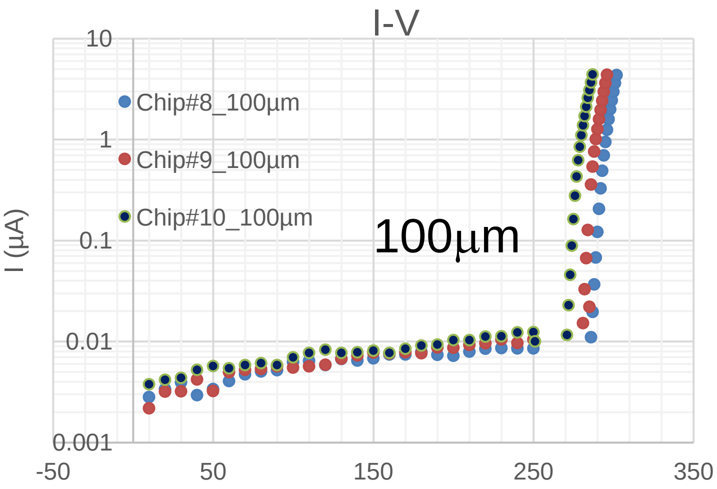


Parameter	1.5 pF	1 pF
Rise Time (from 10% to 90%)	~ 0.9 ns	~ 0.8 ns
Input Referred Noise [estimated from AC simulations]	~ 290 e-	~ 220 e-
Jitter [estimated from $t_r/(S/N)$]	~ 67 ps	~ 44 ps

I,V Curves of MiniCactus

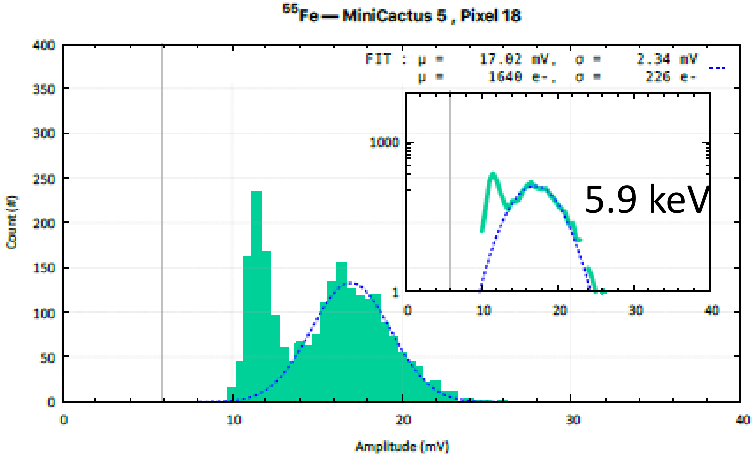


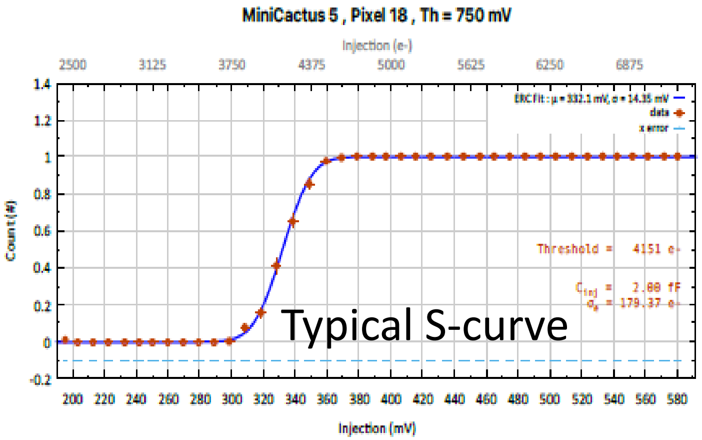


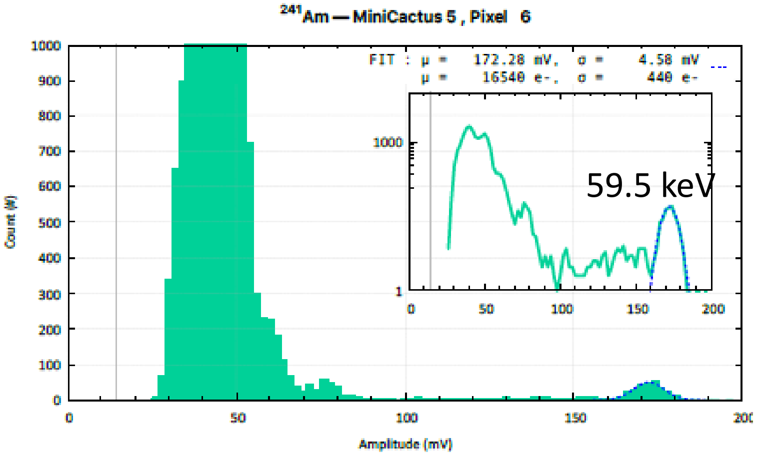


Breakdown voltage from 300 V to 500 V
Variations likely due to post-processing

IN-LAB TESTS (injection pulse, Gamma-ray sources)

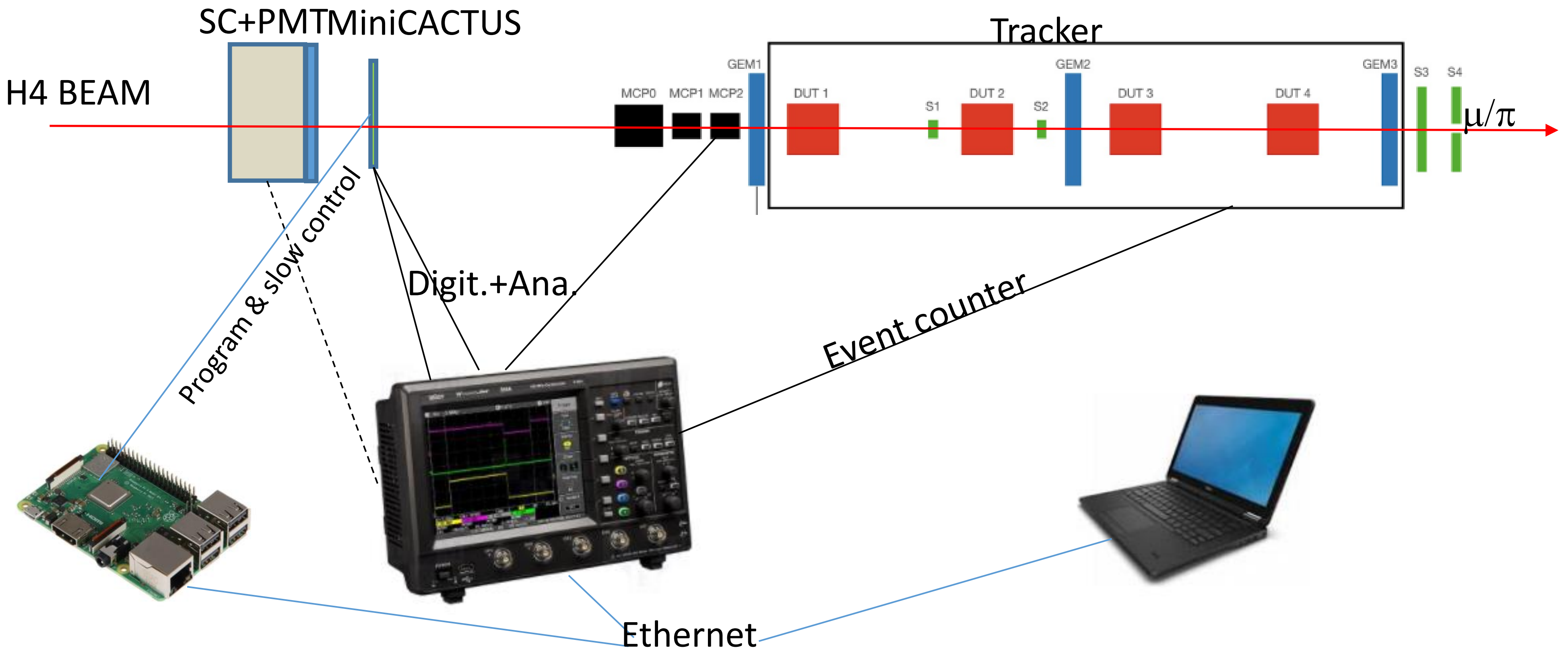






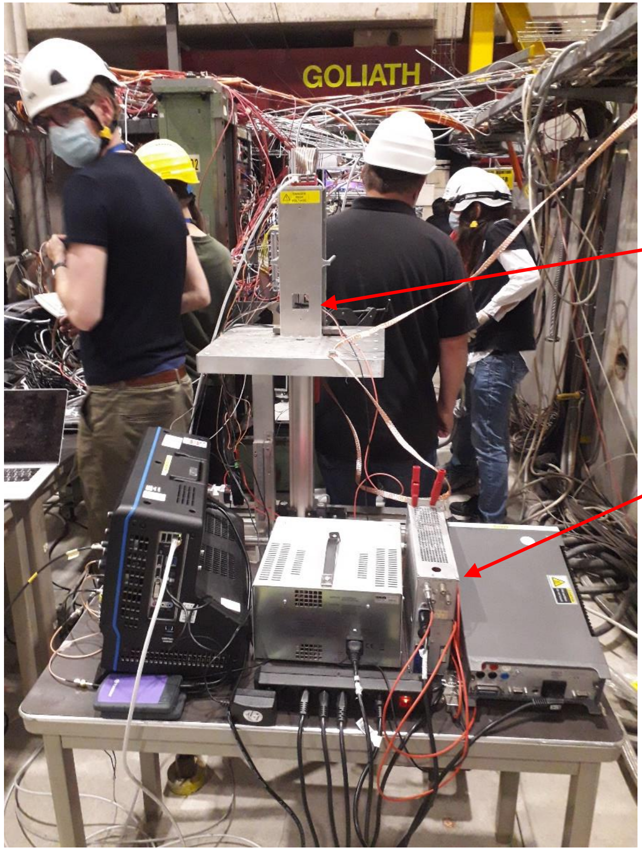
- → Best S/N observed on pixel 8 (0.5mm²) among large pixels
- → Noise$_t$:
  179.4e- (chip#5_200µm)
  155.9e- (chip#8_100µm)

TESTBENCH OF MINICACTUS IN TESTBEAM



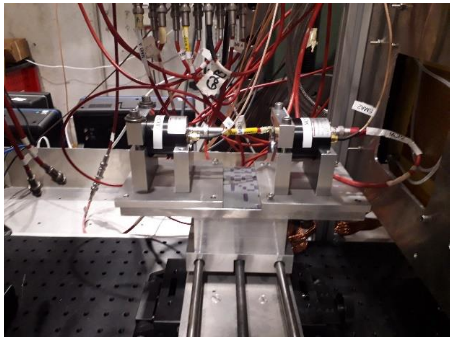
Setup installed on H4 line at SPS-CERN during **RD-51** test-beam periods in **parasitic** mode (October 2021, April 2022, September 2022)

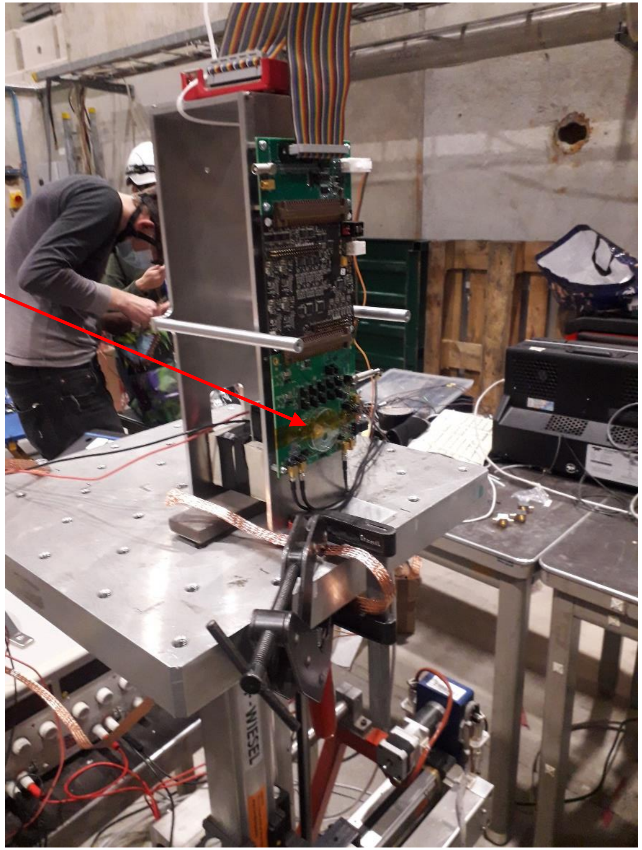
TESTBENCH OF MINICACTUS IN TESTBEAM (RD-51 H4 beamline)



MiniCACTUS

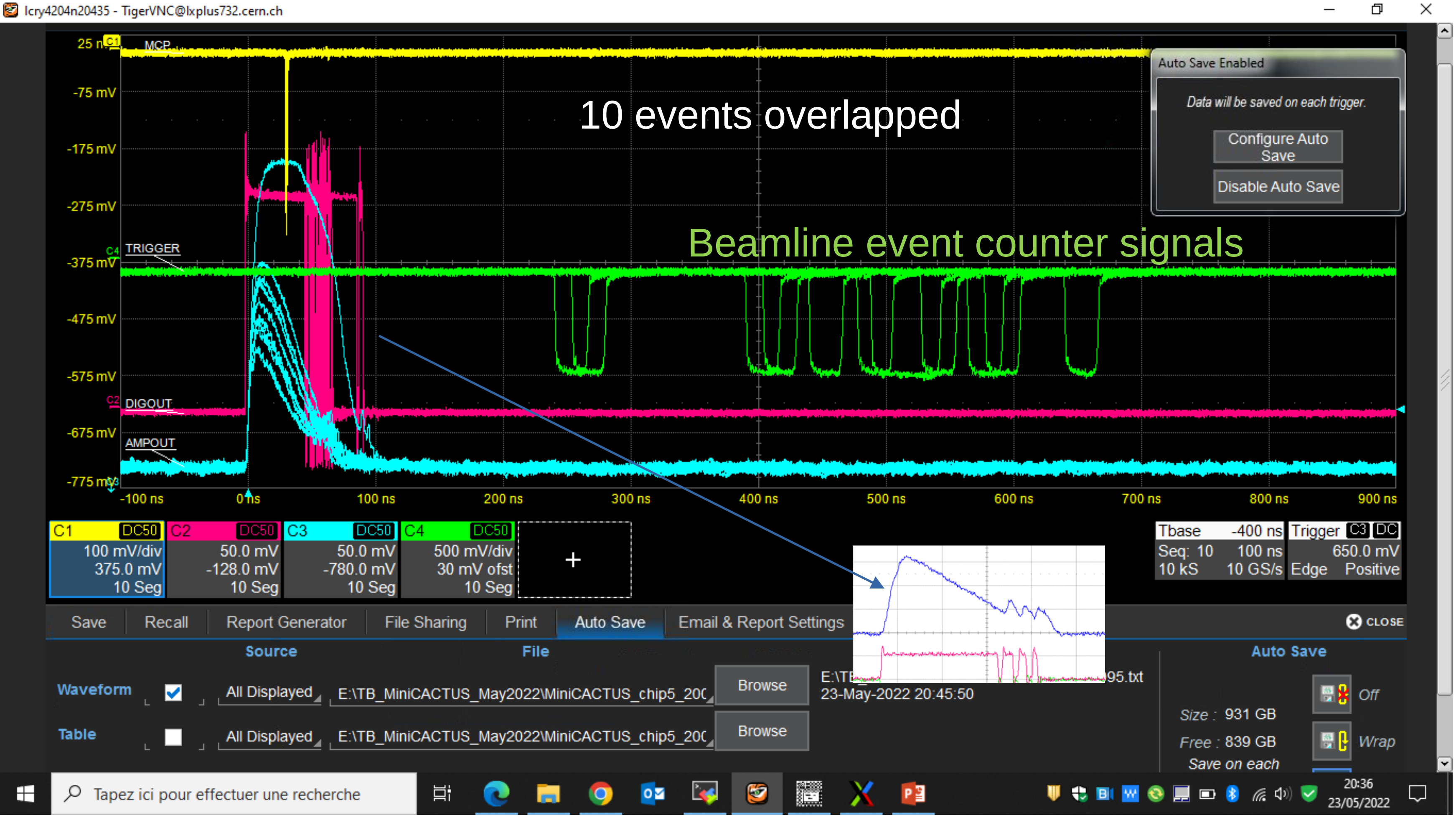
Power Supplies
(LV and HV)





Time reference
RD-51 MCPs (resolution < 10 ps)

TYPICAL WAVEFORMS OBSERVED DURING TESTBEAM

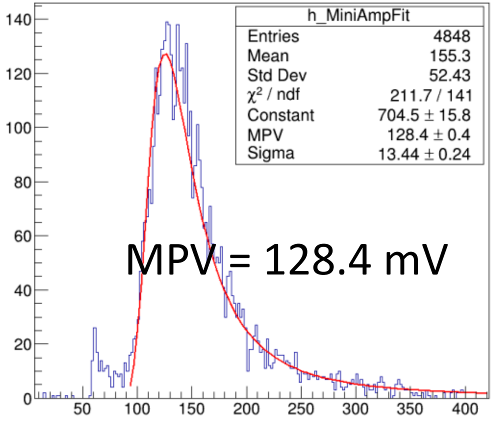


→ Ringing on Digital Output due to coupling from the digital buffers (known problem from in-lab tests, negative impact on TW corrections from digital ToT)

DATA ANALYSIS PROCEDURE

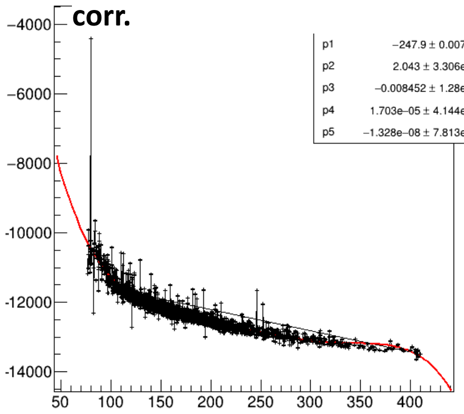
Chip#5, pixel 8**, 0.5 x 1 mm², 200 µm**, **-280V** (Back-side pol.)

MiniCACTUS Analog Monitoring Output



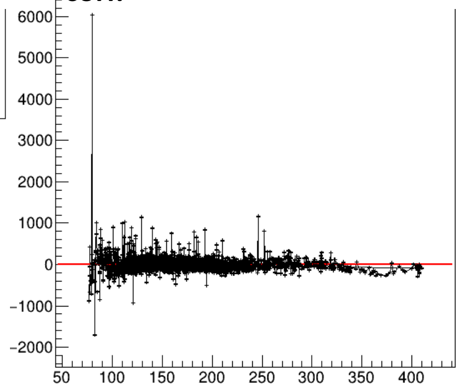
Amplitude (mV)

Fit T_MCP – T_DigOut (ns), no corr.



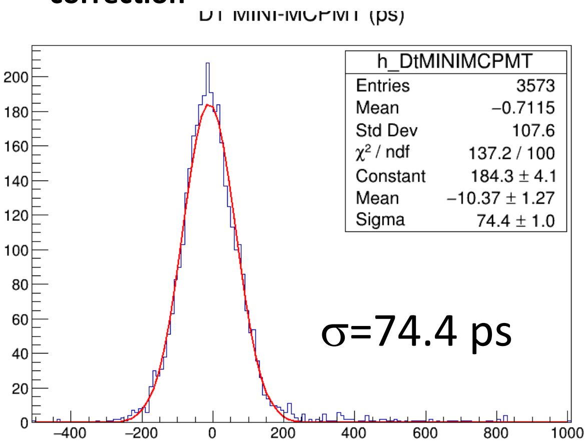
Amplitude (mV)

Fit T_MCP – T_DigOut (ns), TW corr.



Amplitude (mV)

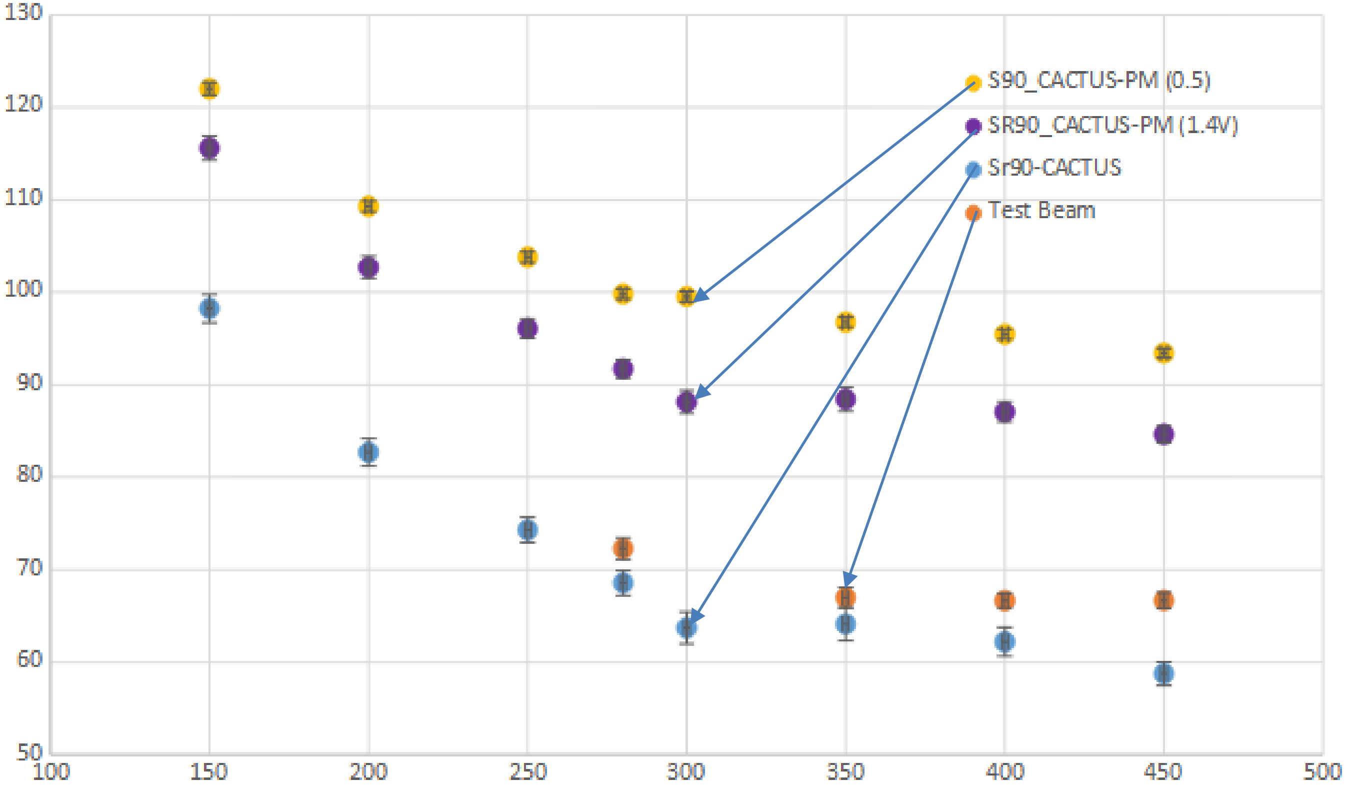
T_MCP – T_DigOut (ps) after TW correction



- Measured timing resolution (-280 V) : **74.4 ps** (MCP resolution negligible)
- Worse timing resolution measured with 100 µm sensor (*lower S/N* and *ringing from digital*)
- Small pixels have worse performance, probably due to charge sharing effects (*pixel 5 , 50 $\mu \times 150\ \mu$ tested in testbeam*)

IN-LAB TIMING MEASUREMENTS WITH PMT AND ^{90}Sr SOURCE

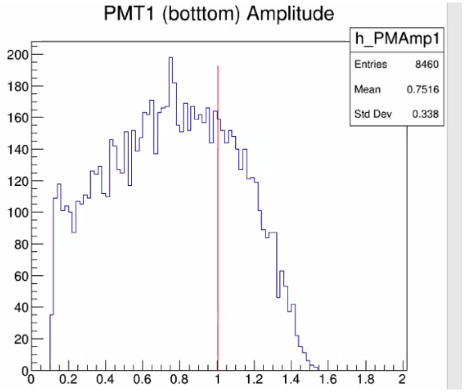
Chip#6, pixel 8**, 0.5 x 1 mm², 200 µm**



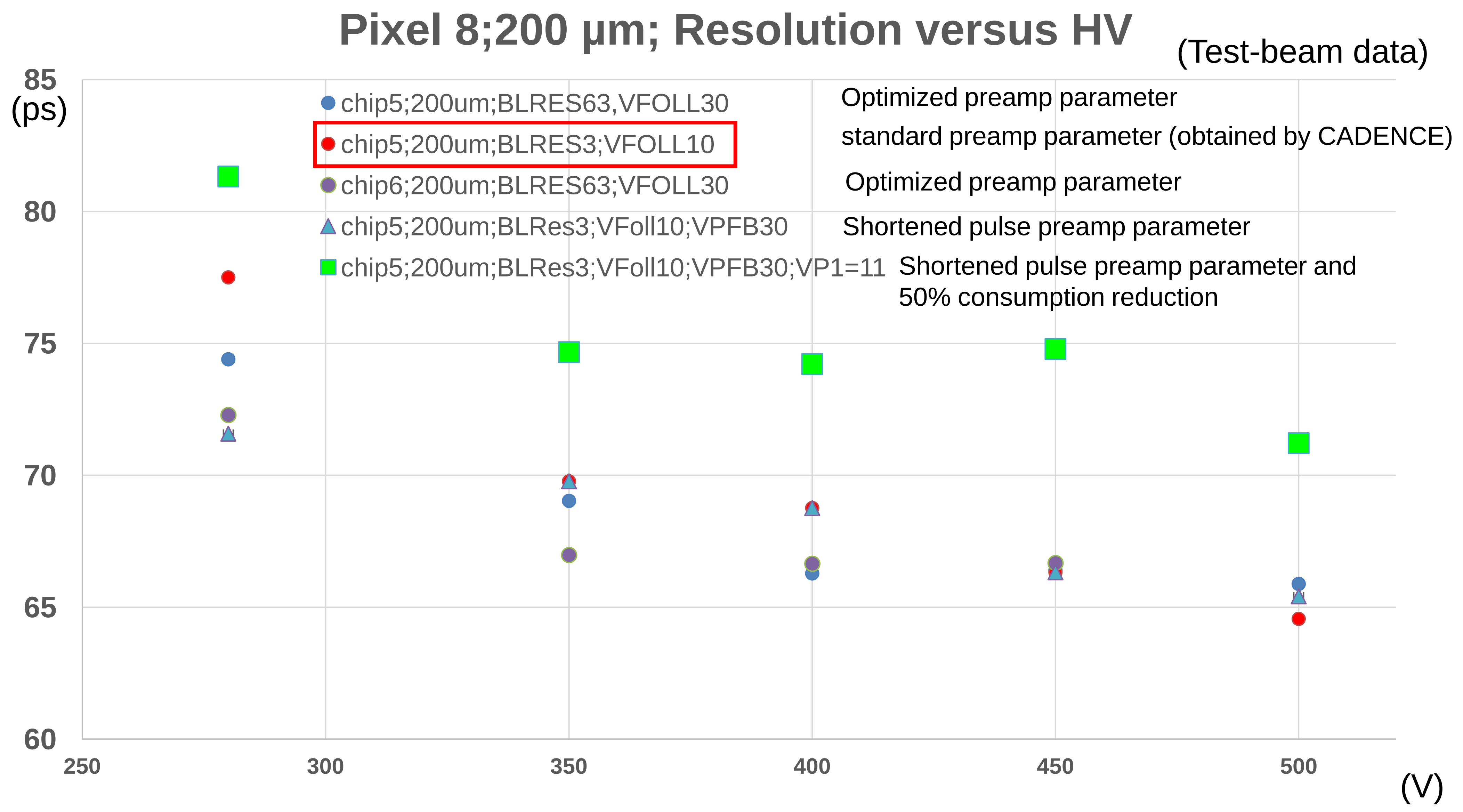
Bias Voltage (V)

→ In-lab measurements with 90Sr betas

allowed to predict actual performance with MIPs



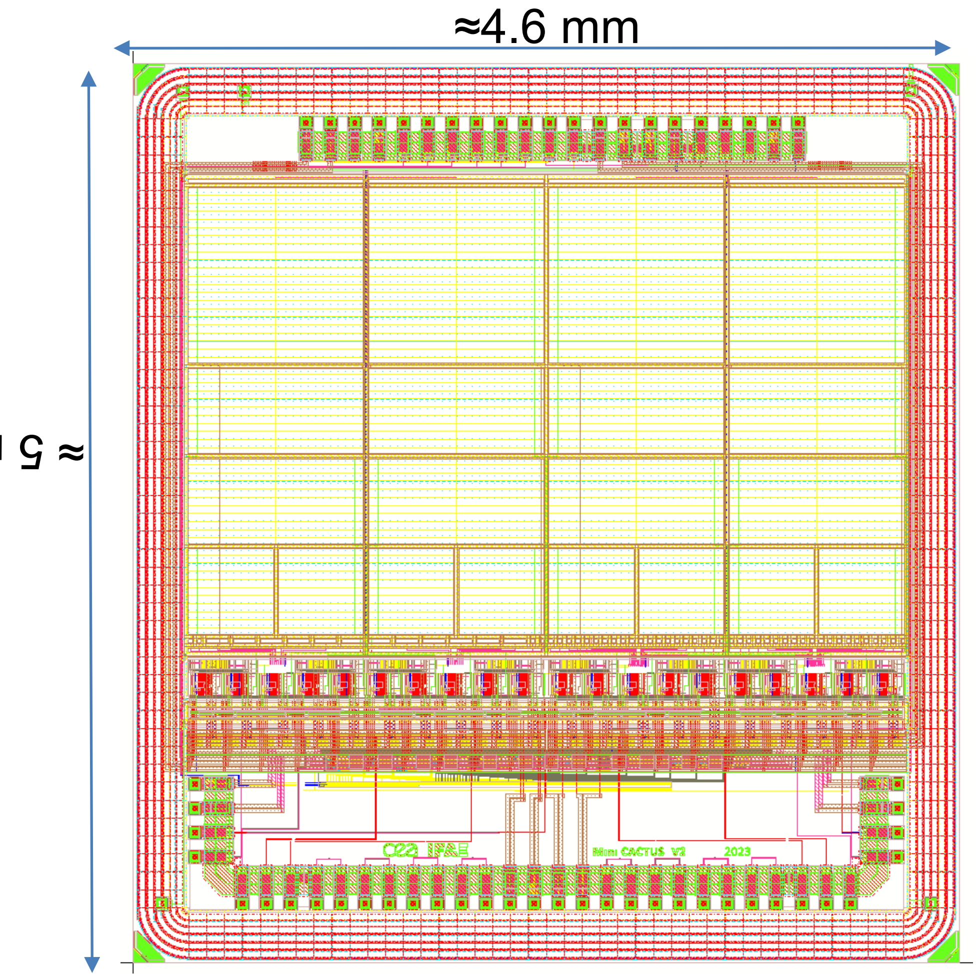
Have to select MIP-like betas by cutting out low energy deposits in PMT



Pixel 8;200 µm; Resolution versus HV
(Test-beam data)
85
(ps)
80
75
70
65
60
250
300
350
400
450
500
(V)
chip5;200um;BLRES63,VFOLL30
chip5;200um;BLRES3;VFOLL10
chip6;200um;BLRES63;VFOLL30
chip5;200um;BLRes3;VFoll10;VPFB30
chip5;200um;BLRes3;VFoll10;VPFB30;VP1=11
Optimized preamp parameter
standard preamp parameter (obtained by CADENCE)
Optimized preamp parameter
Shortened pulse preamp parameter
Shortened pulse preamp parameter and
50% consumption reduction

MiniCACTUS_V2 Sensor Chip

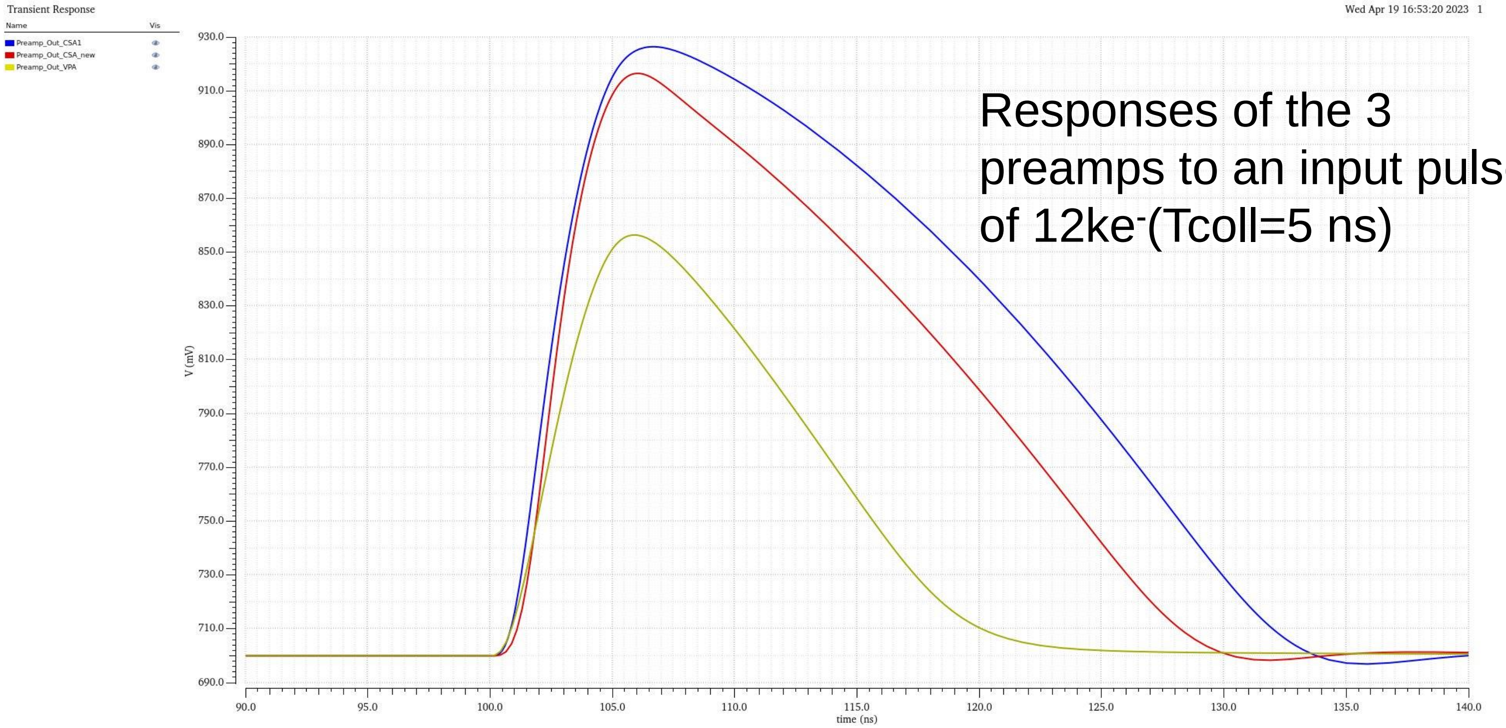
Irfu : Yavuz Degerli, Fabrice Guilloux, Jean-Pierre Meyer, Philippe Schwemling
IFAE : Raimon Casanova, Yujin Gan, Sebastian Grinstein



- ~ 2 times larger than MiniCACTUS
- 0.5 mm x 1 mm (baseline), 1 mm x 1 mm and 0.5 mm x 0.5 mm diodes
- 50 µm x 150 µm and 2 50 µm x 50 µm small test diodes
- 3 different preamps
- New multistage discriminator with **programmable hysteresis**
- Improved layout for better mixed-signal coupling rejection
- **CEA-IRFU** & **IFAE-Barcelona** coll.
- Submitted in May 2023, waiting for samples to
- come back from post-processing

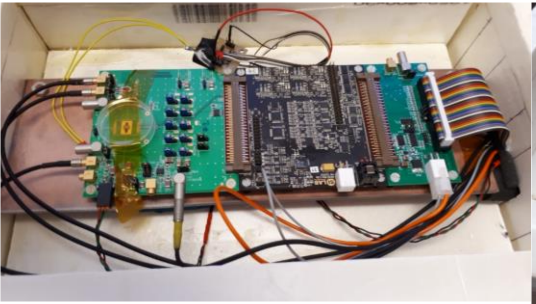
MiniCACTUS_V2 Sensor Chip

- 3 different preamps implemented in MiniCACTUS_V2
- 2 new preamps (CSA_new and VPA) designed by **IFAE-Barcelona** for better jitter and reduced ToT



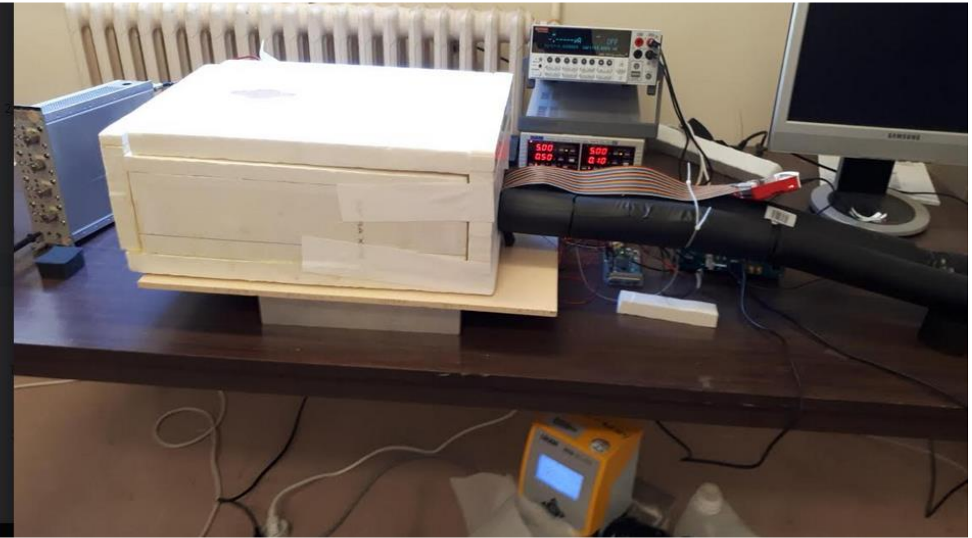
- CSA1 : MiniCACTUS_V1 charge sensitive preamp
- CSA_new : new charge sensitive preamp
- VPA : new voltage preamp

Development of cold box setup



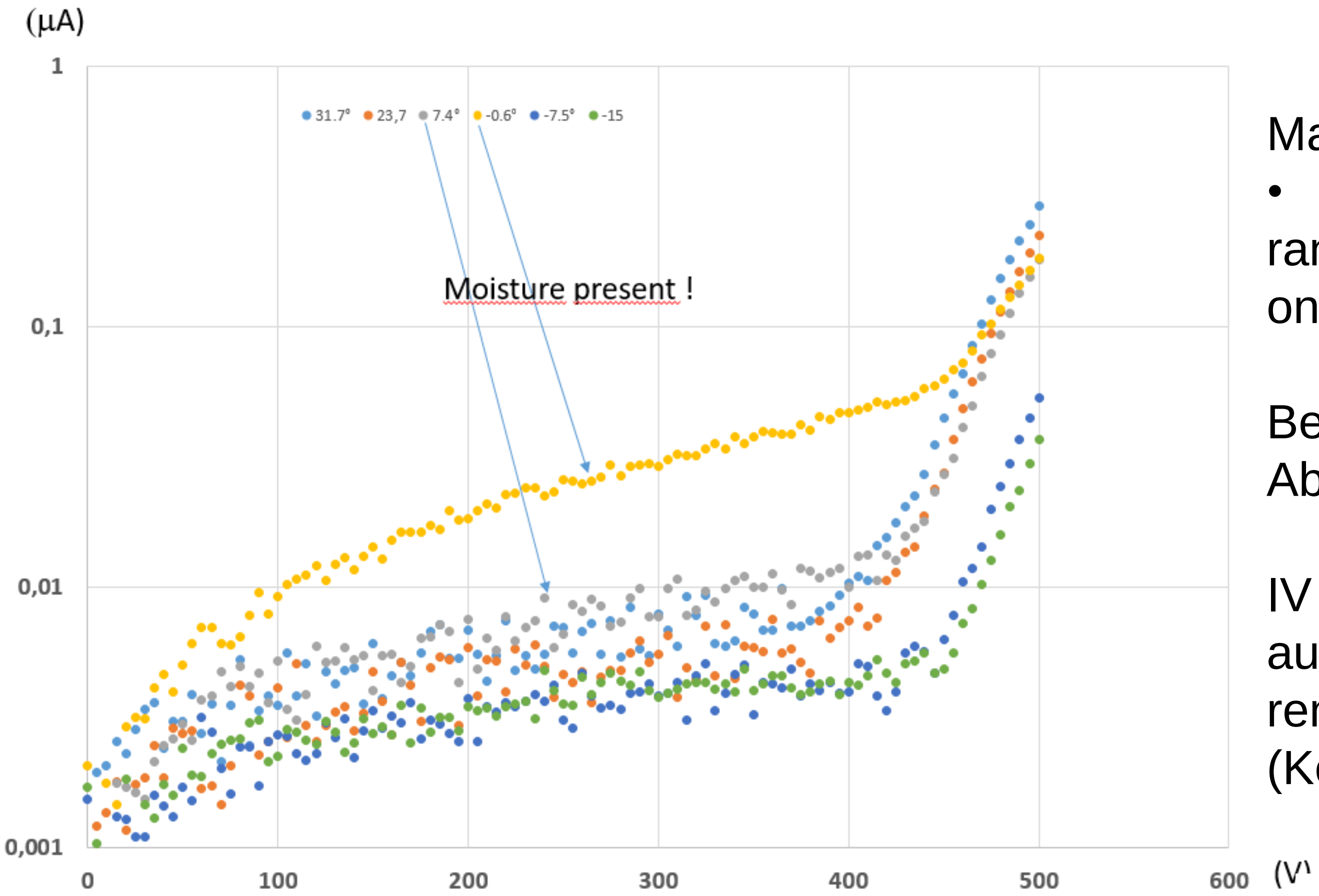
Initial status

After one month of continuous operation at -15°C



- Mostly intended to test irradiated samples
  - We have 100 µ and 300 µ irradiated at 10^{14}, 10^{15}, 10^{16} 1 MeV neq/cm^2
- MiniCactus testbench (DUT board, GPAC, Raspio) in insulating foam box (plus feedthroughs for power and cooling)
- Copper plate with a cooling pipe welded to it plus copper fingers bring cold surface as close as possible to DUT
- Monitoring of temperature and moisture level at various places in cold box
- No moisture control, we just try to minimise water input
- LAUDA chiller, min temp -30°C at chiller output
- Kapton windows allow use of 90Sr beta source (has to stay outside of cold box for safety/regulatory reasons)

IV curves vs temperature (Unirradiated DUT, 300 µ thick)



Main conclusion :

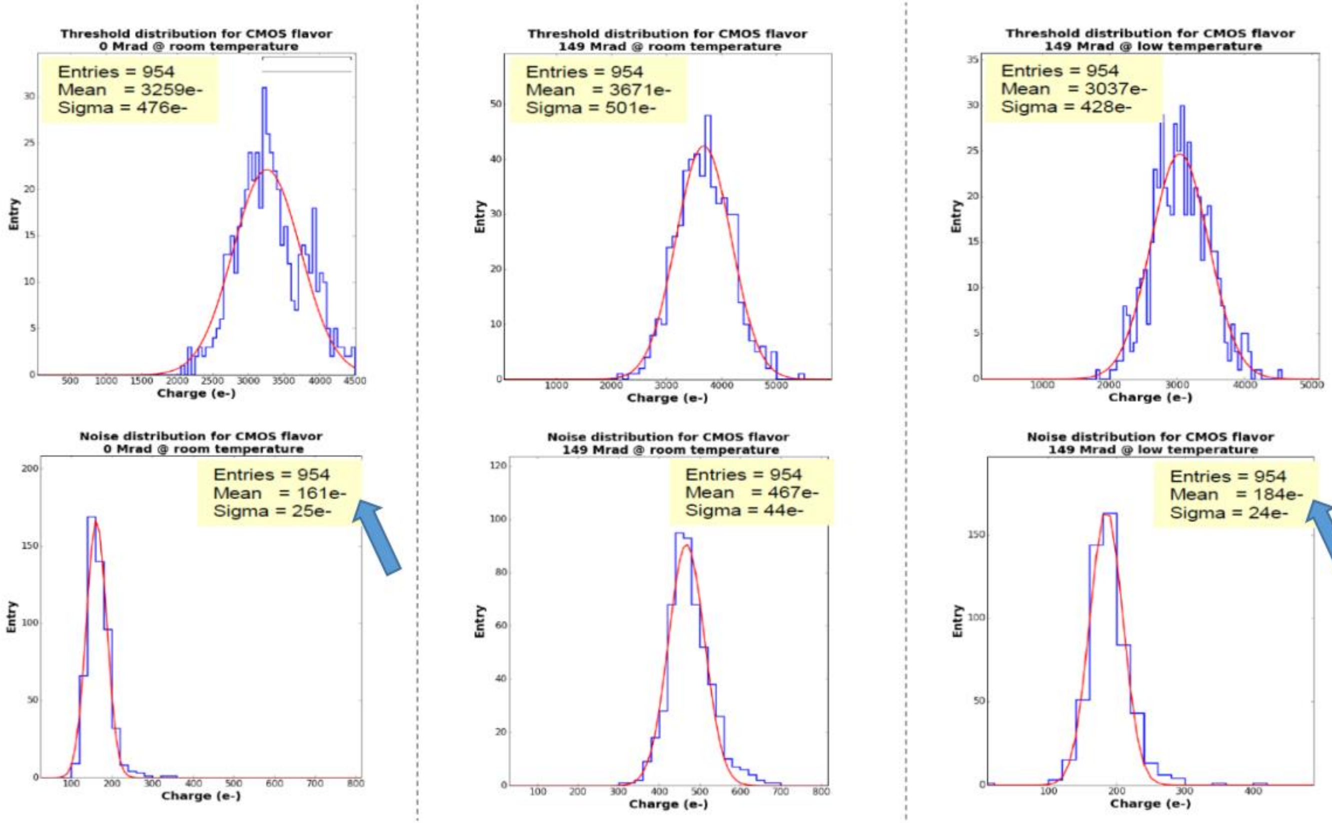
- Need to run avoiding temperature range between 7.5°C and -1°C measure on DUT

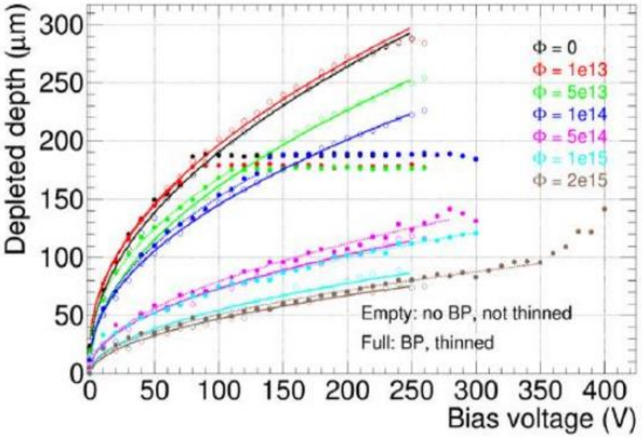
Below -1°C all water is frozen → OK
Above 7.5°C all water is vapour → OK

IV measurement done routinely and automatically through
remote control and monitoring of HV PS
(Keithley sourcemeter)

LF15A radiation hardness

0 Mrad @Room Temp **149 Mrad @Room Temp** **149 Mrad @Low Temp -15°C**





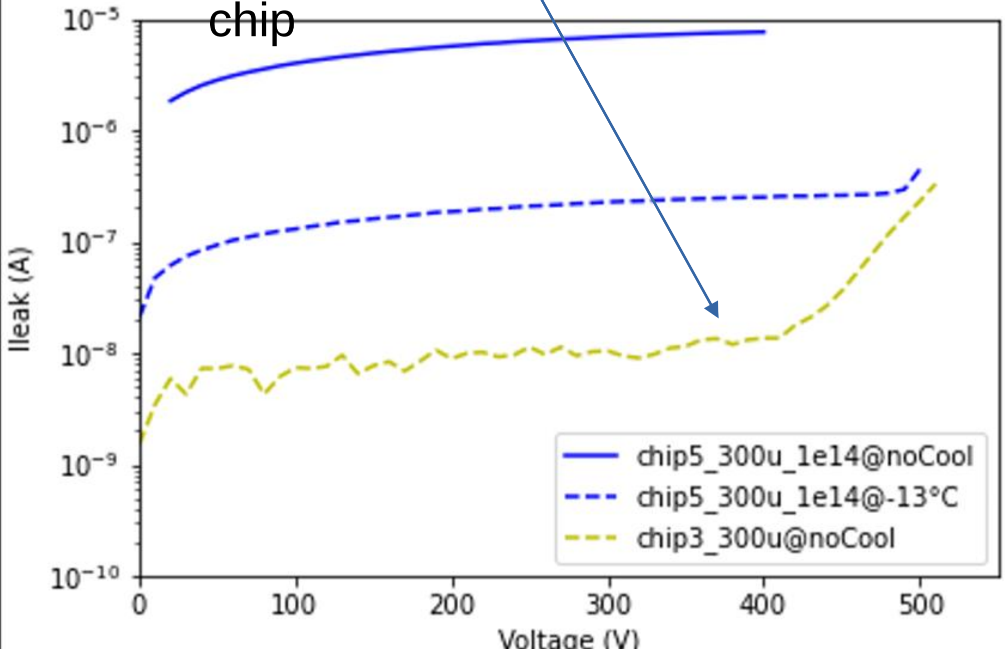
[I. Mandic et al. NIM A 903, 2018]

→ Radiation tests at CERN-SPS with **proton** beam on **LF-CPIX** chip (**CPPM**)

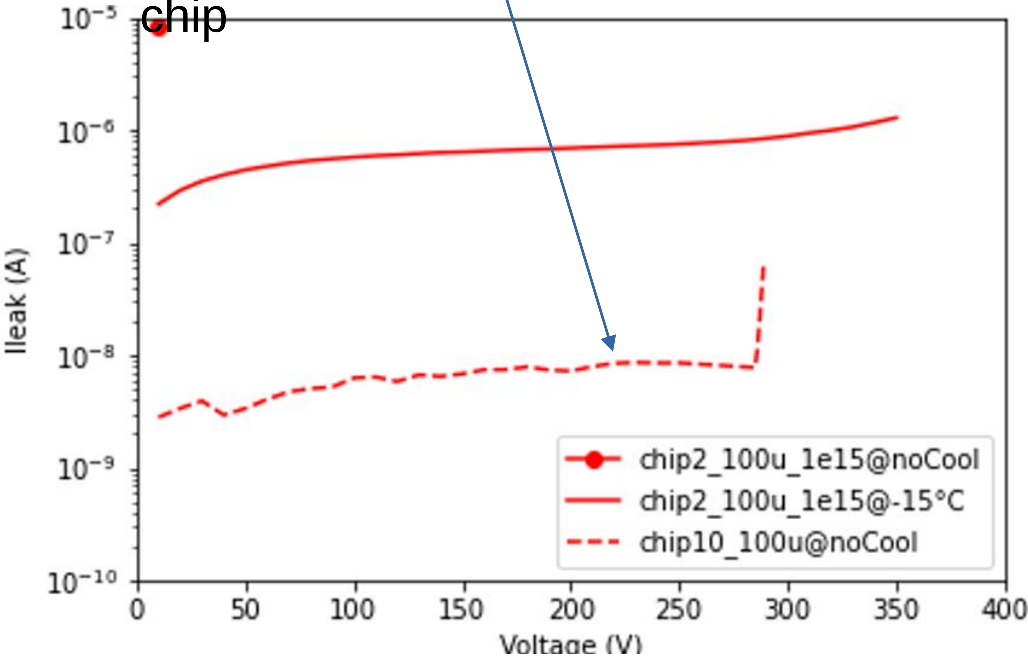
→ 14% increase of noise after irradiation with cooling

IV curves of irradiated MiniCactus v1

Reference 300 μ unirradiated chip



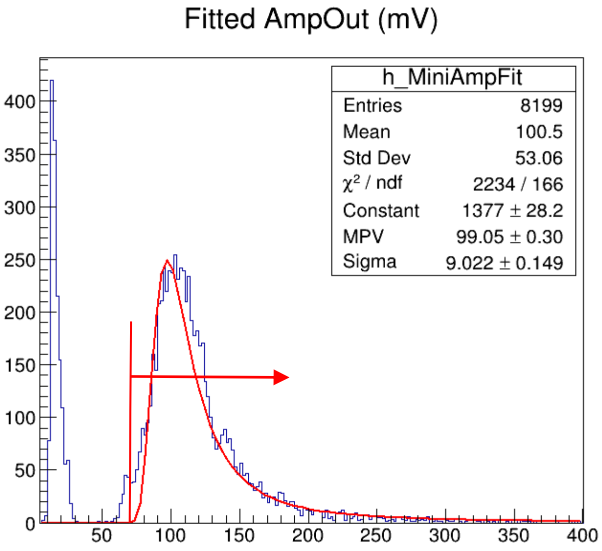
Reference 100 μ unirradiated chip



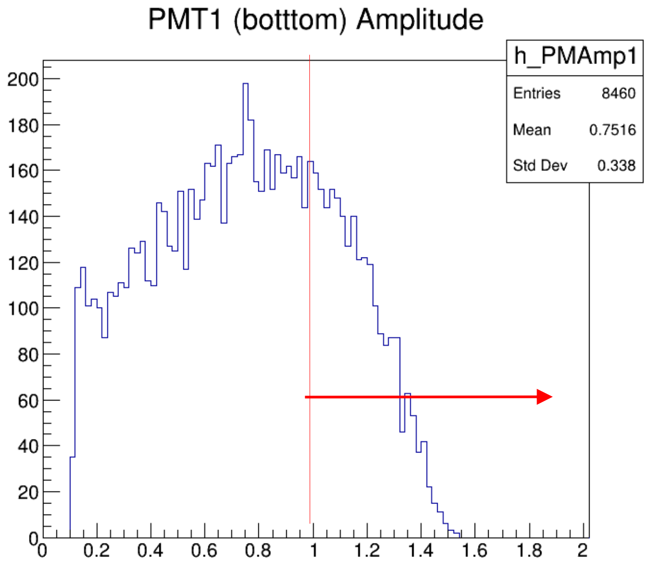
As expected, BV increases with total dose

Cooling is essential to bring leakage current to manageable

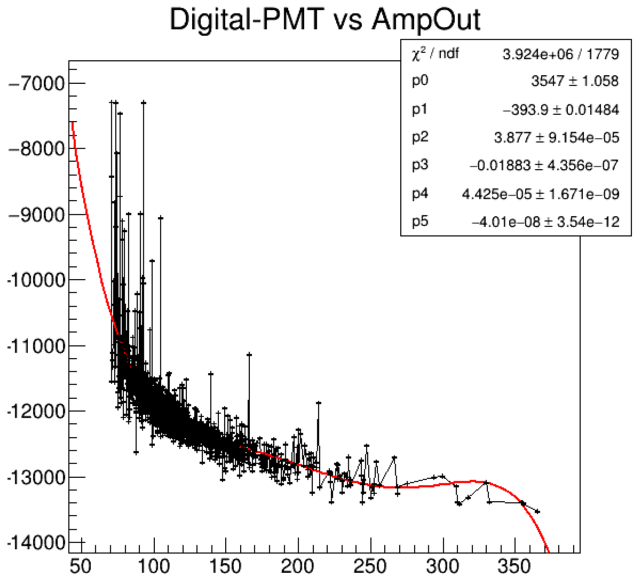
PMT and MiniCactus data
10^{14} 1 MeV neq irradiated DUT, 300 µ thick, 200V



Amplitude (mV)



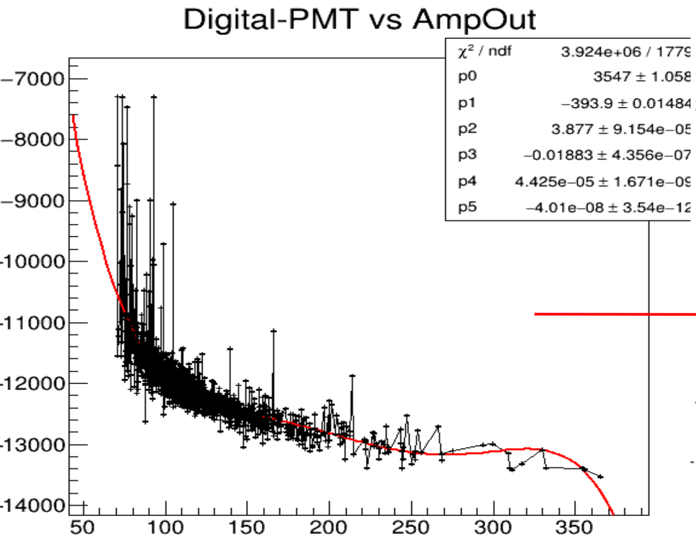
Amplitude (V)

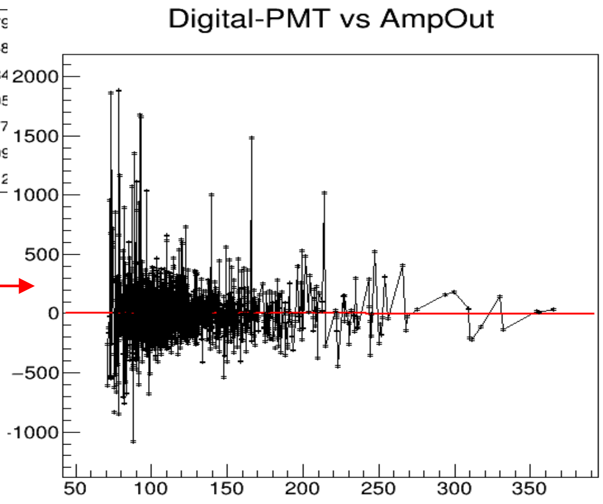


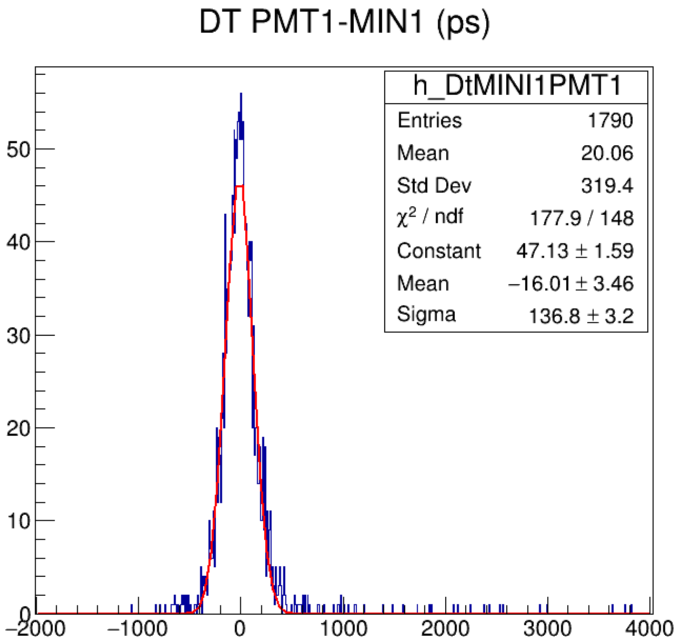
TW correction
As a fct of analog amplitude

PMT and MiniCactus data

10^{14} 1 MeV neq irradiated DUT, 300 µ thick, 200 V







Comparison of time resolution of unirradiated and 10^{14} 1 MeV neq chips

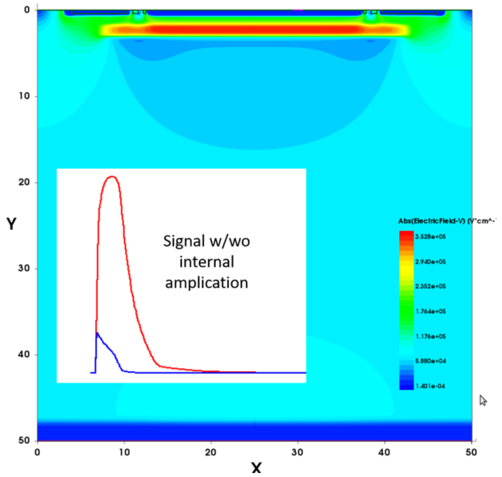
Sensor	HV bias (V)	Conditions	Temp. (°C)	Time res. (ps)	MPV (mV)
Unirradiated 300 u	400	testbeam, MCPMT time reference	room	78.97 ± 1.36	201.9 ± 0.5
Unirradiated 300 u	400	90Sr, PMT time reference*	room	104.5 ± 2.30	195.7 ± 2.3
Unirradiated 300 u	280	testbeam, MCPMT time reference	room	89.11 ± 1.56	200.9 ± 0.5
Irradiated 300 u	280	90 Sr, PMT time reference	20	108.2 ± 3.2 (PMT subt.)	108.2 ± 3.2
Irradiated 300 u	320	90 Sr, PMT time reference	20	132.9 ± 5.0 (PMT subt.)	113.5 ± 0.8
Irradiated 300 u	320	90 Sr, PMT time reference	-15	87.9 ± 4.7 (PMT subt.)	132.7 ± 0.6

Irradiation at 10^{14} n_{eq} worsens time resolution by 18 % w.r.t. unirradiated at 20 °C
Cooling at -15°C brings time resolution more or less back to unirradiated performance (less dark current fluctuations)

*PMT resolution for 90 Sr betas estimated to be 71.3 ps ± 1.7 ps

Conclusions and perspectives

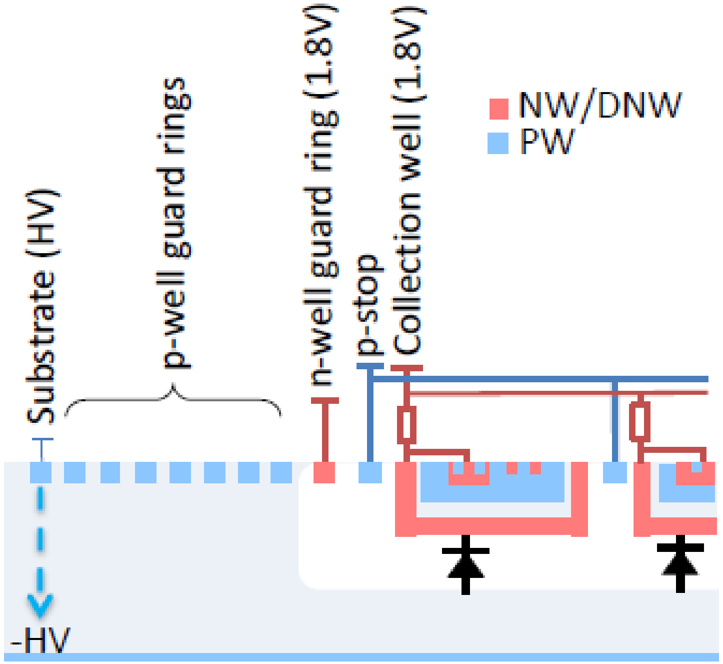
- Short term : evaluation of 10^{15} 1 MeV neq/cm² MiniCactus v1, first results are promising
  - In-lab and test-beam tests of MiniCactus v2. Hope to correct analog/digital coupling and have improved timing performance !
  - Medium term : investigate monolithic pixels with integrated gain layer.
  - Possible with standard LF15A process



- Publications :
  - MiniCACTUS: A 65 ps Time Resolution Depleted Monolithic CMOS Sensor (arXiv:2309.08439, NSS 2022 conference)
  - MiniCACTUS: Sub-100 ps timing with depleted MAPS, Nucl.Instrum.Meth.A 1039 (2022) 167022, VCI 2022 conference)
  - CACTUS: A depleted monolithic active timing sensor using a CMOS radiation hard technology (arXiv:2003.04102, JINST 15 (2020) 06, P06011)

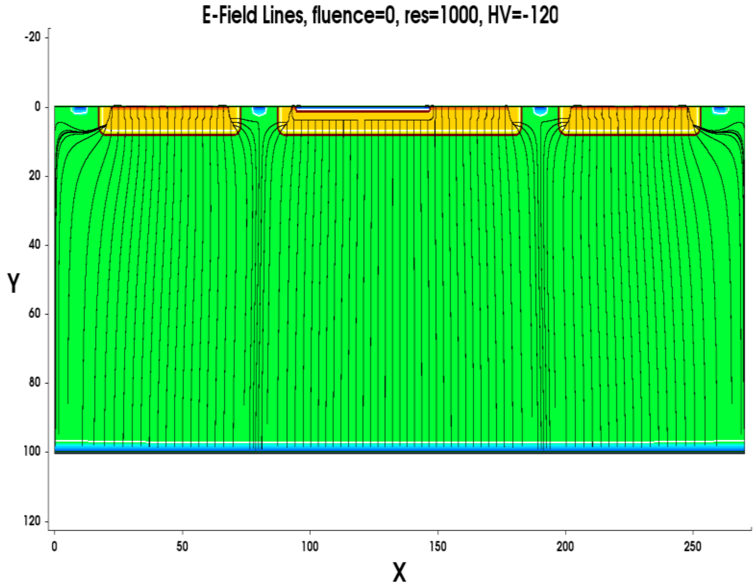
Backup

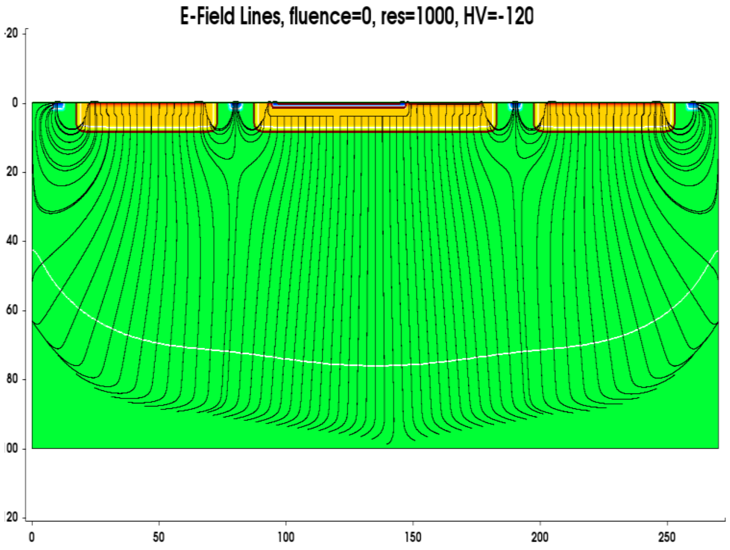
GUARD-RINGS OF LF-MONOPIX1



[M. Barbero et al. JINST 15, 2020]

ELECTRIC FIELDS





Backside versus top biasing → Need backside polarization to ensure best charge collection and signal shape uniformity!

241Am Amplitude Spectrum (pixel 5, 50 µm x 150 µm)